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Second-Hand Tobacco Smoke Exposure in Open and Semi-Open Settings: A Systematic Review

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Abbreviations:

CO carbon monoxide

FCTC Framework Convention on Tobacco Control

IARC International Agency of Research on Cancer

PM Particulate Matter

PPAH polycyclic aromatic hydrocarbons

SHS Second-hand Smoke

WHO World Health Organization

Abstract

Background: Some countries have recently extended smoke-free policies to particular outdoor settings; however, there is controversy regarding whether this is scientifically and ethically justifiable.

Objectives: The objective of the present study is to review research on second-hand smoke (SHS) exposure in outdoor settings.

Data sources: We conducted different searches in PubMed for the period prior to September 2012. We checked the references of the identified papers, and conducted a similar search in Google Scholar.

Study selection: We included combinations of secondhand smoke, environmental tobacco smoke, passive smoking OR tobacco smoke pollution AND outdoors AND PM, PM2.5, RSP, particulate matter, nicotine, CO, cotinine, marker, biomarker OR airborne marker. In total, 18 articles and reports met the inclusion criteria.

Results: Almost all studies used PM2.5 concentration as an SHS marker. Mean PM2.5 concentrations reported for outdoor smoking areas when smokers were present ranged from 8.32 $\mu g/m^3$ to 124 $\mu g/m^3$ at hospitality venues, and 4.60 $\mu g/m^3$ to 17.80 $\mu g/m^3$ at other locations. Mean PM2.5 concentrations in smoke-free indoor settings near outdoor smoking areas ranged from 4 $\mu g/m^3$ to 120.51 $\mu g/m^3$. SHS levels were increased when smokers were present, and outdoor and indoor SHS levels were related. Most studies reported a positive association between SHS measures and smoker density, enclosure of outdoor locations, wind conditions, and proximity to smokers.

Conclusions: The available evidence indicates high SHS levels at some outdoor smoking areas, and at adjacent smoke-free indoor areas. Further research and standardization of methodology is needed to determine whether smoke-free legislation should be extended to outdoor settings.

Introduction

Second-hand smoke (SHS) is a complex mixture of thousands of compounds including particulate matter emitted by the combustion of tobacco products and from smoke exhaled by smokers (IARC 2004). It contains over 50 chemicals recognized as known and probable human carcinogens, other animal carcinogens, and many toxic and irritant agents(US Department of Health and Human Services 2006). Over the past two decades, scientific evidence has accumulated linking SHS exposure to adverse health outcomes, including respiratory outcomes in children and adults, acute cardiovascular effects, and lung cancer (IARC 2004; Ott et al. 2006; US Department of Health and Human Services 2006). Most of this evidence is based on long-term SHS exposure research (IARC 2004). Some recent studies have also reported evidence of effects following short-term exposure to tobacco smoke, such as eye irritation and respiratory irritation among non-smokers (Junker et al. 2001). Even brief and short-term exposures to SHS may generate significant adverse effects on the human respiratory system, as discussed in a recent review (Flouris and Koutedakis 2011). Finally, Pope et al. suggested that effects of acute exposure to tobacco smoke on cardiac autonomic function may contribute to pathophysiological mechanisms linking exposure to SHS to increased risk of cardiovascular mortality (Pope, III et al. 2001).

Smoke-free policies have been expanding worldwide since the World Health Organization (WHO) encouraged countries to follow Article 8 of the Framework Convention on Tobacco Control (FCTC) (WHO 2003) to protect people from SHS (Globalsmokefree Partnership 2009). Legislation has been widely implemented in indoor public places, workplaces, and public transportation (WHO 2009). Since the implementation of indoor smoke-free environments, several studies have demonstrated important reductions of SHS exposure, including an 80–90%

decrease in previously high-exposure settings, such as workplaces and hospitality venues like bars and restaurants (IARC 2008). However, indoor smoking bans may increase the likelihood that smokers will gather at convenient outdoor locations such as public areas near building entrances (Kaufman et al. 2010a). In 2007, a revision of the FCTC Article 8 guidelines further recommended that quasi-outdoor and outdoor public places should be smoke-free under some circumstances, and called upon countries to “adopt the most effective protection against exposure wherever the evidence shows that hazard exists” (WHO 2009). Recently, some countries have extended smoking bans to some outdoor locations (Globalsmokefree Partnership 2009; Repace 2008), particularly health care centers and settings where children are present (Globalsmokefree Partnership 2009). However, there remain some outdoor locations close to smoke-free areas where people may be exposed to SHS, such as terraces and patios in hospitality venues and near entrances to smoke-free buildings (Globalsmokefree Partnership 2009).

Some controversy exists regarding whether smoking should be prohibited in outdoor settings (Chapman 2008;Thompson et al. 2008). Health concerns about SHS exposure, nuisance from SHS, litter, fire hazards, concern about establishing positive smoke-free models for youth, and reducing youth opportunities to smoke (Bloch and Shopland 2000; Brennan et al. 2010; Cameron et al. 2010; Chapman 2008; Repace 2008; Thompson et al. 2008; Thomson et al. 2009) exemplify the reasons why smoking should be banned in selected outdoors locations. Outdoor smoking bans might also support smokers who are trying to quit by limiting their overall cigarette consumption (Williams et al. 2009). Selected outdoor smoking bans should also help to denormalize smoking in outdoor areas (Thompson et al. 2008). In a number of jurisdictions, the majority of the public supports restricting smoking in various outdoors settings, and this support appears to be increasing over time (Thomson et al. 2009). However, those who oppose outdoor smoking bans argue that it is ethically unsustainable because it does not respect the principle of freedom and autonomy of individuals, and that there is insufficient evidence that SHS in these environments has an impact on health (Chapman 2000; Chapman 2008).

SHS exposure has been commonly studied in different indoor locations, especially in workplaces such as hospitality venues or health care centers (IARC 2009); however, outdoor SHS has been scarcely evaluated. It has been hypothesized that the introduction of indoor smoking bans has led to a relocation of smokers to outdoor areas, with a subsequent increase of tobacco smoke levels in outdoor places (Sureda et al. 2011). The aim of the present study is to review research on objectively assessed SHS levels in outdoor settings, including information on indoor and outdoor SHS concentrations, the effect of smoking bans on indoor and outdoor SHS levels, the relation between outdoor and indoor SHS levels, factors that influence outdoor and indoor SHS concentrations, and whether measured SHS levels comply with the Air Quality Standards established by the World Health Organization.

Methods

We conducted several different searches in PubMed for papers published prior to September 2012 to identify papers on SHS assessment in outdoor settings. We combined different terms as follows: ((("Secondhand smoke" OR "environmental tobacco smoke" OR "passive smoking" AND "outdoor") OR ("Tobacco Smoke Pollution"[Mesh] AND "outdoor"))) AND (PM OR RSP OR PM2.5 OR particulate matter OR nicotine OR CO OR cotinine OR marker OR markers OR biomarker OR airborne marker) AND ((English[lang] OR French[lang] OR German[lang] OR Italian[lang] OR Spanish[lang] OR Catalan[lang])). The search was more sensitive than specific; therefore, we performed the first selection of manuscripts by checking the results of every search, and reading titles and abstracts. We then obtained the selected papers and read them carefully. Finally, we completed our search by checking the references of the papers and conducting similar searches in Google Scholar (with search terms in English).

Our final selection included studies whose main objectives were to measure SHS or tobacco smoke exposure in outdoor settings using a tobacco biomarker or airborne marker. Outdoor areas included completely open spaces and quasi-outdoor areas with temporary or permanent structures, such as a roof or side walls, that would impede upward or lateral airflow, respectively.

We excluded articles that studied SHS exposure indoors but not outdoors, and articles that studied air pollution outdoors, but not specifically SHS. We were able to consider papers in the following languages: English, French, German, Italian, Spanish, and Catalan.

Results

Our initial searches identified 263 papers, and after checking the title 67 abstracts were reviewed (Figure 1). Of these, 51 were determined not to meet eligibility criteria. We read the remaining 16 papers in full, plus 6 additional papers identified from references. We finally identified 18 articles and reports that satisfied the inclusion criteria, including 15 published in peer-review journals and 3 academic reports available on the internet. One report was a pilot study for which we obtained data from the subsequently published study (Klepeis et al. 2007). We only included results related to SHS in outdoor areas from another report (CARB 2005) concerning SHS exposure in California.

The 18 papers included were published between 2005 and 2012. They concerned studies conducted in Australia (n = 3), Canada (n = 2), New Zealand (n = 4), the United States (n = 6), Denmark (n=1), and Spain (n=1), and a multicenter study conducted in 8 European countries (n=1) (Table 1). Almost all (n = 16) used airborne markers to assess SHS exposure, including 14 studies that measured particulate matter < 2.5 µm in diameter (PM2.5). Airborne nicotine, carbon monoxide, PM3.5, and polycyclic aromatic hydrocarbons (PPAH) were used infrequently and mostly to complement PM2.5 assessment (n = 5). Two studies used personal biological markers (salivary cotinine in both studies and NNAL in one of the studies) to assess tobacco exposure among participants (Hall et al. 2009; St.Helen et al. 2012).

The studies included between 2 and 127 locations. Depending on the specific study objectives, different locations were tested. Nine studies were conducted in hospitality venues (Table 1) such as pubs, restaurants, bars, cafés and outdoor dining areas. Six studies measured SHS in other locations such as entrances to buildings and the adjacent indoor area; transportation settings, including an airport, parks, streets, university campuses, and one junior college campus (Table 2). Three studies assessed SHS in both hospitality and non-hospitality venues. Most studies were observational studies, with only two experimental studies. All included papers were written in English.

SHS in outdoor smoking areas

Mean PM2.5 concentrations reported for outdoor smoking areas at hospitality venues ranged from 8.32 $\mu g/m^3$ (Stafford et al. 2010) to 124 $\mu g/m^3$ (Wilson et al. 2007) when smokers were present (Table 2). In non-hospitality venues, mean PM2.5 concentrations reported for outdoor settings ranged from 4.60 $\mu g/m^3$ (Boffi et al. 2006) to 17.80 $\mu g/m^3$ (Boffi et al. 2006) (Figure 2). Klepeis et al. (2007) obtained an overall PM2.5 mean of 30 $\mu g/m^3$ for the observational data for hospitality venues and other settings combined. In the experimental component of the same study, PM2.5 concentrations reached values of 200 μg/m^3 and 500 μg/m^3 depending of other external conditions (Klepeis et al. 2007).

Three studies (Cameron et al. 2010; Parry et al. 2011; Stafford et al. 2010) that compared outdoor SHS measurements during smoking and non-smoking periods reported that particulate concentrations were significantly higher during active smoking. Two studies reported that PM2.5 concentrations in outdoor smoking areas were higher than background PM2.5 levels similarly measured in nearby, smoke-free, outdoor air (St. Helen et al. 2011; Travers et al. 2007). An additional study (Boffi et al. 2006) reported high PM2.5 concentrations both outdoors and indoors during a day in a conference center where smoking was permitted.

One study used salivary cotinine to evaluate SHS exposures among nonsmokers before and after they spent six hours at smoking areas of outdoor bars or outdoor restaurants, or an outdoor control site without smoking (Hall et al. 2009). Median increases in salivary cotinine from pre-test to post-test were approximately 162%, 102%, and 16% for the bar, restaurant, and control sites, respectively. A similar study measured salivary cotinine in saliva and NNAL in urine samples from non-smokers before and after being at an outside bar or restaurant, or a control site (St. Helen et al. 2012). Cotinine in samples collected both immediately after and the morning after 3-hr visits to the outside bar and restaurant sites were significantly higher than in control samples, and NNAL was significantly higher in first morning urine samples following bar and restaurant site visits. Another study used airborne nicotine to assess SHS exposure; the mean 8-hour concentrations ranged from 0.013–3.1 μg/m^3 (higher than the mean 8-hour background concentrations of 0.009–0.12 μg/m^3) (CARB, 2005).

Factors influencing outdoor SHS levels

Atmospheric conditions, including wind direction, wind speed, and atmospheric stability, can modify outdoor SHS levels. Other factors are the density and distribution of the smokers and the structure of the outdoor location (completely open or semi-open). All of the studies that evaluated possible modifiers of SHS concentrations reported that the density of smokers and/or number of lit cigarettes predicted outdoor SHS (Brennan et al. 2010; Cameron et al. 2010; CARB 2005; Edwards and Wilson 2011; Kaufman et al. 2010b; Klepeis et al. 2007; Lopez et al. 2012; Parry et al. 2011; Repace 2005; St Helen et al. 2011; St Helen et al. 2012; Stafford et al. 2010; Sureda et al. 2011). Most of these studies also found the degree of enclosure of the outdoor area as a determinant factor (Brennan et al. 2010; Cameron et al. 2010; Lopez et al. 2012; Parry et al. 2011; Stafford et al. 2010; Sureda et al. 2011; Travers et al. 2007). For example, Cameron et al. (2010) reported that PM2.5 increased by approximately 30% with each additional active smoker within 1 m of the point of measurement, and by 50% if measured under an overhead cover.

Some articles that studied wind conditions (speed and direction) and proximity to smokers found that they were not associated with SHS levels (Kaufman et al. 2010b; Travers et al. 2007). However, the CARB study (2005) and two experimental studies (Klepeis et al. 2007; Repace 2005) in public outdoor locations that controlled smoking activity at precise distances from monitored positions reported that outdoor SHS levels were highly dependent on wind direction and source proximity. Kepleis et al. (2007) demonstrated that upwind PM2.5 concentrations are likely to be very low, whereas downwind levels during periods of active smoking can be very high. They also reported that PM2.5 levels decreased by half or more as the distance from a lit cigarette increased from 0.25–0.5 m to 1–2 m, and that levels were generally close to background. However, Repace et al. (2005) reported that outdoor PM3.5 and PPAH concentrations did not approach background levels until about 7 m.

Outdoor smoking areas and indoor air quality

PM2.5 concentrations in indoor settings where smoking was banned but near outdoor smoking areas varied from 4 μg/m^3 (Kaufman et al. 2010b) to 120.51 μg/m^3(Lopez et al. 2012) both studies carried out in hospitality venues. Indoor PM2.5 levels far away from outdoor tobacco sources were lower (Sureda et al. 2011; Wilson et al. 2011).

Two studies specifically examined SHS in main entrances of public buildings. Kaufman et al. (2010) simultaneously measured PM2.5 concentrations inside and outside of 28 office building entrances. Outdoor SHS levels within 9 m of building entrances were significantly higher in the presence of smoking (11 μg/m^3 with 1–4 cig, and 16 μg/m^3 with ≥5 cig) compared to when there was no smoking (8 μg/m^3). PM2.5 median indoor concentrations ranged from 4–6 μg/m^3. Sureda et al. (2011) showed higher median PM2.5 concentrations in the presence of smoking, both outdoors near main entrances (17.16 μg/m^3) and in indoor halls near outdoor smoking areas (18.20 μg/m^3) compared to those in control locations without smoking, both indoors (10.40 μg/m^3) and outdoors (13.00 μg/m^3).

Several articles reported positive associations between SHS levels (PM2.5 concentrations) measured indoors and outdoors (Brennan et al. 2010; Edwards and Wilson 2011; Kaufman et al. 2010b; Lopez et al. 2012; Sureda et al. 2011; Wilson et al. 2011). Indoor SHS levels are higher when smoking occurs in the adjacent outdoor setting, especially when the outdoor area is semi-enclosed. For example, Sureda et al. (2011) showed that PM2.5 concentrations in indoor halls were more closely correlated with outdoor concentrations measured near main entrances (outdoors) than with the indoor control (a non-smoking area far from the main entrance). Brennan et al. (2010) estimated that a 100% increase in the geometric mean of the outdoor PM2.5 concentration was associated with a 36.1% rise in the geometric mean of the indoor PM2.5 concentration in smoke-free pubs and bars.

Factors influencing indoor SHS from outdoor areas

Factors such as wind speed and direction that modify outdoor SHS levels also may influence indoor air quality. The effects of structural barriers between outdoor smoking areas and indoor locations were also considered in some articles (Brennan et al. 2010; Edwards and Wilson 2011). Brennan et al. (2010) observed that open access between indoors and outdoors was associated with lower PM2.5 levels indoors. However, an Australian study (Edwards and Wilson 2011) showed higher indoor PM2.5 concentrations when doors to outdoor smoking areas were left open.

Smoking bans and SHS exposures

One study evaluated the impact of indoor smoke-free laws (Brennan et al. 2010) by measuring PM2.5 concentrations before and after indoor smoking bans were implemented in pubs and bars that had at least one indoor area with an adjacent semi-enclosed outdoor eating/drinking area, and showed reduced PM2.5 concentrations both indoors and outdoors (65.5% and 38.8%, respectively) from pre-ban to post-ban. Two other studies evaluated indoor and outdoor SHS in different settings after the implementation of indoor smoke-free laws (Wilson et al. 2007; Wilson et al. 2011). Both reported higher concentrations of fine particulates in outdoor smoking areas, especially those that were partly enclosed, as well as indoor areas adjacent to outdoor smoking areas compared to other smoke-free indoor settings. Finally, a multicentre study carried out in hospitality venues of 8 European countries compared SHS concentrations between venues where indoor smoking was allowed and venues where it was banned. They reported that median indoor PM2.5 and airborne nicotine concentrations were significantly higher in venues where smoking was allowed than those where it was banned. Conversely, the outdoor nicotine concentration was significantly higher for venues where indoor smoking was banned than outdoor areas of venues where indoor smoking was allowed (Lopez et al. 2012).

Tobacco smoke levels compared to background levels

Maximum mean or median outdoor PM2.5 concentrations ranged from 128 $\mu g/m^3$ (Sureda et al. 2011) to 496 $\mu g/m^3$ (Kaufman et al. 2010b), with some point measurements exceeding 1000 $\mu g/m^3$ (Klepeis et al. 2007; Travers et al. 2007). The maximum peak indoor PM2.5 concentration reported for a smoke-free setting was 239 $\mu g/m^3$ (Wilson et al. 2011). In contrast, mean or median background PM2.5 concentrations varied from 6 $\mu g/m^3$ (Travers et al. 2007) to 20.4 $\mu g/m^3$ (St Helen et al. 2011).

SHS markers other than PM2.5

Three studies evaluated different SHS markers to determine which would be most appropriate to describe SHS levels in outdoor areas. Sureda et al. (2011) reported a Spearman correlation coefficient between outdoor PM2.5 and airborne nicotine concentrations of 0.365 (95% CI: 0.009–0.650). Hall et al. (2009) reported that the number of smokers present had a strong positive association with outdoor PM2.5 concentrations, but not CO concentrations. Moreover, CO levels measured outside restaurants and bars did not differ significantly from concentrations measured at a control location, in contrast with findings for PM2.5 concentrations. Other studies used biological markers such as cotinine or NNAL to show SHS exposure (Hall et al. 2009; St Helen et al. 2012).

Discussion

We found only 18 studies that met our criteria, but the indicated that SHS levels in some outdoor smoking areas are not negligible, especially in areas that are semi-enclosed.

SHS levels and Air Quality Standards

In general, SHS levels measured in outdoor smoking areas were high, particularly in hospitality venues where PM2.5 concentrations ranged from 8.32 $\mu g/m^3$(Stafford et al. 2010) and 182 $\mu g/m^3$ (Hall et al. 2009) when smokers were present. SHS levels were also increased in indoor areas adjacent to outdoor smoking areas. Hall et al. (2009) and St Helen et al. (2012) reported that saliva cotinine concentrations were higher in study participants following exposure to SHS at outdoor bars and restaurants when smoking was allowed, than after exposure to smoke-free terraces. These results suggest that hospitality workers and patrons may be exposed to high SHS levels under certain conditions. Although outdoor SHS levels are more transient than indoor levels, and can quickly drop to background levels in the absence of active smoking, potential health effects of these exposures merit consideration and need to be further studied.

According to the WHO, there is no safe level of SHS (WHO, 2000). The WHO guidelines indicate that the lower range of concentrations at which adverse health effects have been demonstrated is not greatly above background concentrations (estimated at 3–5 $\mu g/m^3$ in the United States and Western Europe for PM2.5). In the updated WHO Air Quality Guidelines, an annual outdoor average value of 10 $\mu g/m^3$ for PM2.5 was selected as the lower end of the range over which significant effects on survival have been observed (Gorini et al. 2005; WHO 2005; WHO 2000). These are the lowest levels at which total, cardiopulmonary, and lung cancer mortality have been shown to increase with more than 95% confidence in response to PM2.5. .

Most of the reviewed studies of PM2.5 concentrations in outdoor smoking areas reported levels higher than the annual mean guideline value of 10 μg/m^3 recommended by WHO

Influences of outdoor SHS on indoor air quality

Indoor smoke-free areas near outdoor smoking areas showed higher levels than smoke-free indoor areas that were farther away from outdoor SHS sources, suggesting that SHS from outdoor smoking areas can enter adjacent buildings. Some findings also suggested that, while outdoor SHS concentrations dropped immediately to background levels when the SHS sources were extinguished, indoor SHS concentrations persisted at relatively high levels and slowly decayed over several hours until doors were opened to ventilate the building (Klepeis et al. 2007). SHS levels in outdoor locations are more susceptible to variation due to the proximity of active smoking and wind conditions. During periods of active smoking, outdoor SHS levels can be comparable to levels in indoor smoking areas, but outdoor levels dropped rapidly after smoking activity ceased.

Other factors influence SHS levels

Some factors can influence SHS levels both indoors and outdoors (Brennan et al. 2010; Cameron et al. 2010; Edwards and Wilson 2011; Kaufman et al. 2010b; Klepeis et al. 2007; Lopez et al. 2012; Repace 2005; St Helen et al. 2011; St Helen et al. 2012; Stafford et al. 2010; Sureda et al. 2011). Smoker density and enclosure of the outdoor locations are determinant modifiers. Some studies also suggest that wind speed and direction, as well as proximity to smokers, are associated with SHS levels outdoors.

SHS airborne markers other than PM2.5

Particulate matter was the most common airborne marker used in the presently reviewed articles. However, PM2.5 it not a specific marker; markers such as airborne nicotine are specific to SHS (Gorini et al. 2005;Ott et al. 2006). Biological markers have been scanty used. However, cotinine has been proposed as a very sensitive and specific biological marker of SHS exposure(Benowitz 1999) and total NNAL has been used to characterize human exposure to carcinogenic tobacco-specific nitrosamines among non-smokers exposed to SHS (Anderson et al. 2001). Further research is necessary to evaluate which SHS marker would be most appropriate to measure SHS levels in outdoors settings and if it would be necessary to combine more than one marker.

Limitations

Some of the reviewed studies did not control for important factors that can influence SHS levels, such as wind conditions, the structural characteristics of outdoor area (semi-enclosed vs. totally open), or proximity to active smokers. Future studies should control for these factors to enable a better understanding of the results. Additionally, some studies used PM2.5 concentrations to estimate SHS levels in outdoor areas, but did not control for other sources of PM2.5, such as cooking or traffic-related air pollution (Gorini et al. 2005). Further studies should record the presence of other sources of combustion, such as cooking facilities, proximity to roadways, or traffic density, measure and report background levels of PM2.5, and/or use specific SHS markers such as airborne nicotine.

Publication bias is a potential source of error in systematic reviews. We searched the available literature in PubMed, the main biomedical database, and Google Scholar, and checked references to identify documents not published in academic journals. However, we cannot rule out the possibility that some non-published manuscripts or other documents addressing the topic of interest may have been missed. Direct comparisons of results among studies were hampered by the use of different statistics (medians, means, or geometric means) and sampling strategies; the use of standardized methods could strengthen the validity of results and facilitate comparisons among different populations and locations. Furthermore, the number of venues measured in each study was limited. Future studies should consider including representative samples of locations selected using standard statistical sampling procedures and sample size computations.

Strengths

The reviewed studies included a variety of venue types (entrances to public buildings, hospitality venues, transportation settings, etc.) and characteristics. Most of the reviewed studies were observational, and thus provide information that reflects smoking behaviors and exposures under normal real-life conditions. However, experimental studies provide the opportunity to control for unpredictable variables, such as the proximity of smokers or wind conditions. The use of real-time monitoring permits determination of the precise magnitude of extremely transient (short-term) concentrations and exposures, while retaining the flexibility of exploring concentrations and exposure across a variety of averaging times and time series, and calculating mean concentrations and exposures (Klepeis et al. 2007).

Conclusion

Only limited evidence is available regarding SHS exposure in outdoor settings as determined by environmental and biological markers; therefore, the existing evidence must be interpreted carefully. However, our review clearly indicates the potential for high SHS exposures at some outdoor settings and indoor locations adjacent to outdoor smoking areas. This review shows that high smoker density, highly enclosed outdoor areas, low wind conditions, and close proximity to smokers generate higher outdoor SHS concentrations. Accounting for these factors is important for future studies on the relationship between outdoor SHS exposure and health outcomes.

The WHO Framework Convention on Tobacco Control has concluded that 100% smoke-free environments are required to adequately protect the public's health from the harmful effects of SHS (WHO 2003). The present review indicates that further research using standardized methodology is needed to better characterize outdoor SHS exposure levels and determine whether smoke-free legislation should be extended to outdoor areas.

Future studies should include representative samples of different locations; use standardized statistical analyses and report multiple measures of central tendency and measures of variability (standard errors, confidence intervals or quartiles); and consider potential modifiers of SHS levels including smoker density, degree of enclosurement of outdoor locations, wind speed and direction, and proximity to smokers. Finally, further research is needed to determine the most appropriate marker or combination of markers to assess SHS exposure, which may include more specific environmental and individual markers of exposure (e.g., airborne nicotine and cotinine in saliva) in addition to PM2.5 concentration.

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Table 1. Main characteristics of reviewed studies from before September 2012 assessing outdoor second-hand smoke (SHS) exposure in hospitality venues.

First author, location, publication year	Study design, venue type and sample size	SHS marker	Potential confounders	SHS marker concentration: Presence of smokers	SHS marker concentration: Absence of smokers	Background concentration (control)
Klepleis, N. California, USA; 2007	Observational and experimental. Ten outdoor public places including parks, sidewalk cafés, and restaurant and pub patios. Note: Results provided for hospitality venues and other settings combined	PM2.5	Wind conditions, source proximity, and number of cigarettes	Overall mean: 30 μg/m^3 (observational data). Max.: 1000 μg/m^3 at distances within 0.5 m (experimental data)		
Travers, M. Victoria, British Columbia, Canada; 2007	Observational. Twenty smoking areas: bars, and restaurants (outdoors)	PM2.5	Number of burning cigarettes, coverage and cigarette proximity, or size	Overall mean: 96 μg/m^3. Max.: 1318 μg/m^3		6 μg/m^3
Wilson, N. New Zealand; 2007	Observational. Thirty-four pubs, restaurants, and bars; six outdoor smoking areas of bars and restaurants. Also in this study: 10 transportation settings; nine other indoor settings; and six other outdoor settings (see Table 2)	PM2.5	Number of people in room/area and number of lit cigarettes among occupants	"Outdoor" smoking areas of bars and restaurants (n=4): 36 μg/m^3. Relatively enclosed smoking areas attached to bars (n=2): 124 μg/m^3. Max. (outdoor smoking area in a bar): 284 μg/m^3	Inside hospitality venues (n=34): 16 μg/m^3. Outside hospitality venues (n=34): 14 μg/m^3	14 μg/m^3

First author, location, publication year	Study design, venue type and sample size	SHS marker	Potential confounders	SHS marker concentration		Background concentration (control)
				Presence of smokers	Absence of smokers	
Hall, J.C. Athens, Georgia, USA; 2009	Observational. Five bars (n=3) and family restaurants (n=2) (outdoors)	Salivary cotinine	Proximity to smokers	Overall geometric mean (GM) Bar: 182 $\mu g/m^3$. Overall GM Restaurant: 75 $\mu g/m^3$	Overall GM Bar: 69 $\mu g/m^3$. Overall GM Restaurant: 36 $\mu g/m^3$	Before smoking time: 43 $\mu g/m^3$. After smoking time: 49 $\mu g/m^3$
Brennan E. Victorias, Australia; 2010	Observational. Nineteen pubs and bars that had at least one indoor area with an adjacent semi-enclosed outdoor eating/drinking area (5 m from the main access)	PM2.5	Number of patrons and lit cigarettes, overhead covers, ventilation, and kitchen operating	Overall GM Indoor: 61.3 $\mu g/m^3$ (pre-ban). Overall GM Outdoor: 19.0 $\mu g/m^3$ (pre-ban)	Overall GM Indoor: 17.4 $\mu g/m^3$ (post-ban). Overall GM Outdoor: 13.1 $\mu g/m^3$ (post-ban)	
Cameron, M. Melbourne, Australia; 2010	Observational. Sixty nine visits to 54 dining areas of bars and restaurants	PM2.5	Number of target cigarettes, number of other lit cigarettes, and overhead cover	Overall mean: 27.3 $\mu g/m^3$. Max.: 483.9 $\mu g/m^3$	Overall mean: 17.6 $\mu g/m^3$	8.4 $\mu g/m^3$
Stafford, J. Perth and Mandurah, Australia; 2010	Observational. Twelve cafes and 16 pubs (outdoors)	PM2.5	Number of smokers, wind level, coverage, number of patrons, street type, and road traffic	Overall median: 8.32 $\mu g/m^3$. Max.: 142.08 $\mu g/m^3$	Overall median: 2.56 $\mu g/m^3$	

First author, location, publication year	Study design, venue type and sample size	SHS marker	Potential confounders	SHS marker concentration: Presence of smokers	SHS marker concentration: Absence of smokers	Background concentration (control)
Edwards, R. New Zealand; 2011	Observational. Seven pubs and bars (semi-enclosed outdoor area and indoor)	PM2.5	Ventilation	Non-communication smoking area outdoors: range of 32 -109 μg/m^3. Communication smoking area outdoors: range of 29 -192 μg/m^3	Non-communication smoking area indoors: range of 14 - 79 μg/m^3. Communication smoking area indoors: range of 2.36 -117 μg/m^3	
St Helen, G. Athens, Georgia, USA; 2011	Observational. Two family restaurants, three bars (outdoors)	PM2.5 and CO	Number of smokers, pedestrians, and vehicles	PM2.5: range of 16.6 and 63.9 μg/m^3. CO: range of 1.2 and 1.6 ppm		PM2.5: 20.4 μg/m^3. CO: 1.3 ppm
Wilson, N. New Zealand; 2011	Observational. Twenty outdoor smoking areas of hospitality venues; 13 inside bars adjacent to outdoor smoking areas; ten pubs/sports bars; 18 bars; nine restaurants; five cafés. Also in this study: 15 inside public buildings; 15 inside transportation settings; and 22 various outdoor street/park settings	PM2.5	None	Outdoor smoking areas of hospitality venues (n=20): 72 μg/m^3. Inside bars adjacent to outdoor smoking areas (n=13): 54 μg/m^3	Inside hospitality venues (n= 42): range of 7 -22 μg/m^3	11 μg/m^3
St Helen, G. Athens, Georgia, USA; 2012	Observational. A bar and a family restaurant (outdoors). An open air seating area with no smokers (control).	Salivary cotinine (SC) and NNAL	Number of lit cigarettes	SC in restaurant: 69 μg/m^3. SC in bar: 165 μg/m^3. NNAL in restaurant: 0.774 μg/m^3. NNAL in bar: 2.407 μg/m^3	SC in restaurant: 46 μg/m^3. SC in bar: 45 μg/m^3. NNAL in restaurant: 0.041 μg/m^3. NNAL in bar: 0.037 μg/m^3	SC: 53 μg/m^3. NNAL: 0.038 μg/m^3

First author, location, publication year	Study design, venue type and sample size	SHS marker	Potential confounders	SHS marker concentration		Background concentration (control)
				Presence of smokers	Absence of smokers	
López, M.J. Europe; 2012	Observational. Forty eight hospitality venues (night bars, restaurants and bars)	PM2.5 and nicotine	Number of smokers and coverage	PM2.5 indoors (n=42): 120.51 µg/m^3 (pre-ban). PM2.5 outdoors (n=42): 29.61 µg/m^3(pre-ban). Nicotine indoors (n=46): 3.69 µg/m^3(pre-ban). Nicotine outdoors (46): 0.31 µg/m^3 (pre-ban)	PM2.5 indoors (32): 36.90 µg/m^3 (post-ban). PM2.5 outdoors (32): 36.10 µg/m^3 (post-ban). Nicotine indoors (39): 0.48 µg/m^3 (post-ban). Nicotine outdoors (39): 1.56 µg/m^3 (post-ban)	

Table 2. Main characteristics of reviewed studies from before September 2012 assessing outdoor second-hand smoke (SHS) exposure in non-hospitality settings.

First author, location, publication year	Study design, venue type and sample size	SHS marker	Potential confounders	SHS marker concentration		Background concentration (control)
				Presence of smokers	Absence of smokers	
CARB, California, USA; 2005	Observational. An airport, a junior college campus, a public building, an office complex, and a park	Airborne nicotine	Number of cigarettes smoked, wind speed and direction	Range of 0.013–3.1 μg/m^3		Range of 0.009–0.12 μg/m^3
Repace, J. Baltimore, USA; 2005	Experimental. Various locations on the UMBC campus (outdoors and indoors)	PM3.5 and PPAH	Distances, number of smokers, and wind conditions	Range of 100–150 μg/m^3 outdoors in proximity to smokers		
Boffi, R. Copenhagen, Denmark; 2006	Observational. In a car park, inside a non-smoking conference center, outdoors in front of the conference center, with smokers under a roof, along the motorway, and inside a Copenhagen restaurant where smoking was allowed	PM2.5	None	Outside in front of a conference Center: 17.8 μg/m^3. Along the motorway: 4.6 μg/m^3	Car parking area: 6.0 μg/m^3. Inside a conference center: 3.0 μg/m^3	5.7 μg/m^3

First author, location, publication year	Study design, venue type and sample size	SHS marker	Potential confounders	SHS marker concentration		Background concentration (control)
				Presence of smokers	Absence of smokers	
Klepleis, N. California, USA; 2007	Observational and experimental. Ten outdoor public places including parks, sidewalk cafés, and restaurant and pub patios. Results provided for hospitality venues and other settings combined	PM2.5	Wind conditions, source proximity, and number of cigarettes	Overall mean: 30 μg/m^3. Max.: 1,000 μg/m^3 at distances within 0.5 m		
Wilson, N. New Zealand; 2007	Observational. Ten transportation settings; nine non-hospitality indoor settings and six non-hospitality outdoor settings. Also in this study: 34 pubs, restaurants, and bars and six outdoor smoking areas of bars and restaurants	PM2.5	Number of people in room/area and number of lit cigarettes among occupants		Transportations settings (n=10): 13 μg/m^3. Non-hospitality indoors (n=9): 3 μg/m^3. Non-hospitality outdoors (n=6): 7 μg/m^3	14 μg/m^3
Kaufman, P. Toronto, Canada; 2010	Observational. Entrances to 28 office buildings both indoor and outdoor	PM2.5	Number of cigarettes, wind direction and strength, and distance from the nearest lit cigarette to the monitor	Overall median Outdoors: 11 μg/m^3 (1–4 cig); 16 μg/m^3 (≥ 5 cig). Max.: 496 μg/m^3. Overall median Indoors: 6 μg/m^3 (1–4 cig); 4 μg/m^3 (≥5 cig)	Overall median Outdoors: 8 μg/m^3. Overall median Indoors: 5 μg/m^3	8 μg/m^3
Parry, R. New Zealand; 2011	Observational. Streets (number of samples not indicated)	PM2.5	Number of smokers, smoking proximity, and coverage	Overall mean: 14.2 μg/m^3. Max.: 186.0 μg/m^3	Overall mean: 5.9 μg/m^3	

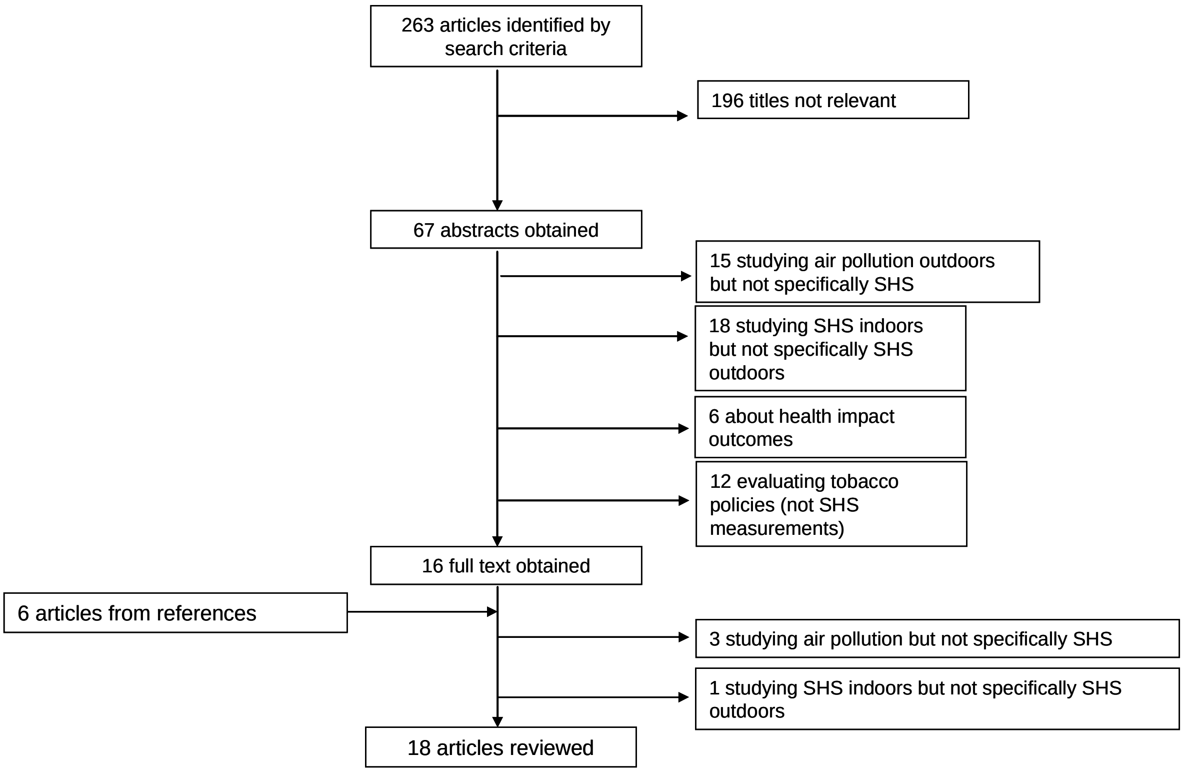
First author, location, publication year	Study design, venue type and sample size	SHS marker	Potential confounders	SHS marker concentration		Background concentration (control)
				Presence of smokers	Absence of smokers	
Sureda, X. Barcelona, Spain; 2011	Observational. Forty seven public building main entrances (both outdoors and indoors)	PM2.5 and airborne nicotine	Number of lit cigarettes, Coverage, and distance to roadways	Overall PM 2.5 concetration Outdoor: 17.16 μg/m^3. Overall PM2.5 concentration Indoor: 18.20 μg/m^3. Nicotine concentration in 28 main entrances outdoors: 0.81 μg/m^3. Max value PM2.5 (outdoor): 128.44 μg/m^3	Overall PM2.5 concentration Control point indoor: 10.40 μg/m^3	PM2.5 concentration: 13.00 μg/m^3
Wilson, N. New Zealand; 2011	Observational. Fifteen inside public buildings; 15 inside transportation settings; and 22 various outdoor street/park settings. Also in this study: 20 outdoor smoking areas of hospitality venues; 13 inside bars adjacent to outdoor smoking areas; ten pubs/sports bars; 18 bars; nine restaurants; and five cafés	PM2.5	None		Inside non-hospitality settings (n= 30): Range of 2 - 13 μg/m^3. Non-hospitality outdoor settings: Range of 2-11 μg/m^3	11 μg/m^3

FIGURE LEGENDS

Figure 1. Flow diagram for the identification and selection of studies included in the review.

Figure 2. Outdoor PM2.5 concentrations reported for hospitality venues and other settings according to the presence or absence of smokers. The study by Klepleis et al.(2007) included hospitality and non-hospitality venues without distinguishing the mean value between them, and hence it has been included both in “hospitality venues” and “othervenues”. The studies by Wilson et al. (2011) and Edwards & Wilson (2011) provided the individual values for each measurement and we have computed the arithmetic mean for the figure. The studies by Brennan et al. (2010) and Lopez et al. (2012) provided mean and median values, respectively, for venues before and after a smoking ban. We have computed the average values for each study to include them the figure.

Figure 1. Derivation of 18 articles reviewed.



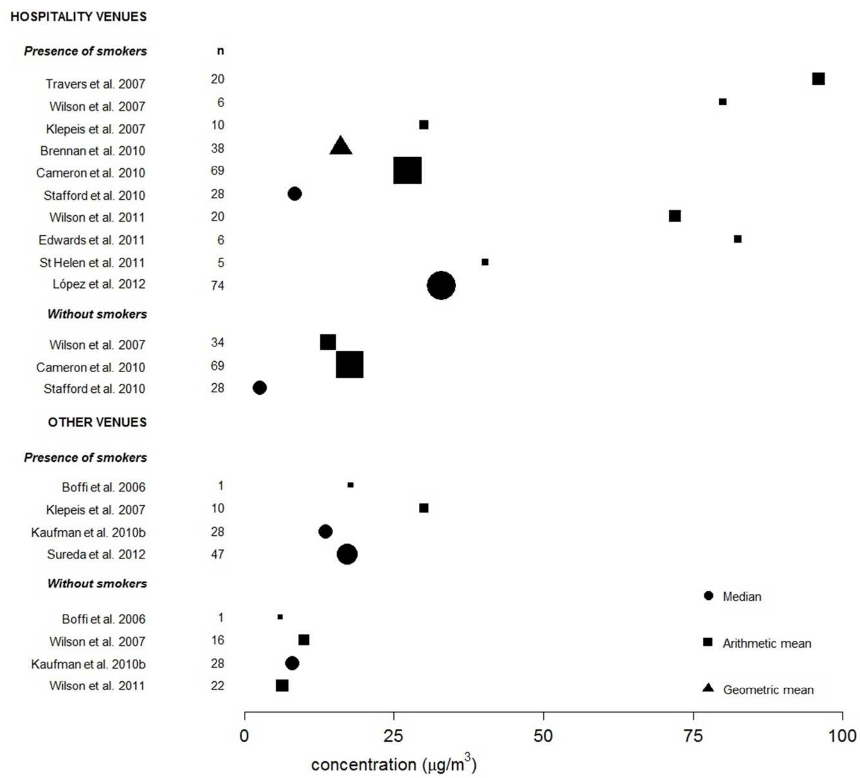


Figure 2

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